ICD for the

HST Robotic Vehicle (HRV)

to Grapple Arm (GA)

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1 SCOPE AND CONTEXT

This ICD contains information and requirements concerning the integration of the manipulator subsystem, robotic interfaces and ground station for the Grapple Arm (GA) into the HRV mission.

The following verbs, as used in this document, have the specific meaning as indicated below:

"shall"	Indicates a mandatory requirement.
"should"	Indicates a preferred but not mandatory alternative.
"may"	Indicates an option.
"will"	Indicates a statement of intention or fact.

2 SPECIFICATIONS ANDF STANDARDS

Document	Title
ISO/IEC 14772-1:1997	The Virtual Reality Modeling Language. International Standard (VRML97)
TIA/EIA-RS170A	Monochrome Television Studio Facilities, Electrical Performance Standards, Electrical Industries Association
MIL-STD-461C	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
TIA/EIA-422B	Electrical Characteristics of Balanced Voltage Digital Interface Circuits

3 DEFINITIONS AND INTERFACES

3.1 Item Definition

3.1.1 Functions

The Grapple Arm (GA) is a subsystem of the Space Telescope Advanced Robotic Servicing System (STARSS) for the Hubble Robotics Vehicle (HRV). STARSS is defined as the STARSS Ground Segment (SGS), the GA, and the Dexterous Robot (DR). The GA is capable of performing the following functions:

a) HST capture, positioning the HST at the HRV berthing interface, and release.

b) DR capture, resource (power, data, video) transfer, positioning and support (load reaction) while the DR operates at the HST servicing worksites.

c) Video image capture, storage and transfer

3.1.2 Composition

The GA is comprised of the following major assemblies:

a) Manipulator Arm (MA) consisting of joints, booms, end effecter, cameras and lights; the Manipulator Control Unit (MCU) for manipulator control and vision processing; and the interconnecting cable between the MCU and the MA.

b) STARSS Ground Station (SGS) for planning and supervision of the robotic operations.

3.1.3 Mission Profile

The GA space segment will be designed for the mission profile in Table 1.

3.1.4 Manipulator Subsystem States

To support the mission profile in Section 3.1.3, the GA provides the following states with the functions described in Table 2. The allowable state transitions are shown in Figure 2.

a) Off State

b) Initialize State

c) Standby State

d) Operate State

3.1.5 HRV Axes

Axes defined in this specification should be interpreted in accordance with TBS. Note that the origin of axes is not shown and is defined as required in specific paragraphs. MDR may use different axes and reference frames for the design, analysis and test of the GA.

3.2 Physical Interfaces

3.2.1 Flight Interfaces

3.2.1.1 Mechanical Interfaces

3.2.1.1.1 GA to HRV

a) The stowed configuration of the GA will not exceed the static envelope identified in Appendix A1.

b) The GA shall be attached and connected via the interfaces defined in Appendix A1.

c) The GA will be designed to survive launch loads that shall be determined by the HRV Systems Integrator in a coupled dynamic loads analysis. The GA attachment points are defined in Appendix A1. The HRV Systems Integrator is responsible for the design, production and installation of the hold-down latches at the attachment points identified in Appendix A1. Preliminary analysis shall use the load factors defined in the generic Evolved Expendable Launch Vehicle (EELV) Payload Planners Guide (PPG).

d) The GA will not generate on-orbit operating loads greater than 180 N and 1360 Nm at the shoulder interface.

e) The GA shall be designed to operate from a mounting interface of stiffness greater than 3.6e6 N/m, 2.4e6 Nm/radians, in and about any axis (including any thermal isolation required).

f) The GA shoulder interface operating range will be –35 to +40 deg C.

g) The HRV Systems Integrator shall ensure that heat transfer across the shoulder interface is less than 5.0 W/degC throughout the operating temperature range defined in 3.2.1.1.1 f).

3.2.1.1.2 GA to HST Flight Releasable Grapple Fixture (FRGF)

a) The GA will interface with the HST FRGF as defined in Appendix A1.

b) The GA will not generate on-orbit operating loads greater than the GA - HST FRGF interface thresholds defined in Appendix A1.

c) The approach envelope to the HST FRGF will be as described in Appendix A1.

d) The HST GF mounted stiffness is as per Appendix A1.

3.2.1.1.3 GA to DR

a) The GA will interface with the DR via the interface defined in Appendix C.

b) The approach envelope to the DR grapple fixture shall be as described in Appendix C.

3.2.1.1.4 MCU to HRV

a) The MCU will not exceed the envelope defined in TBS.

b) The MCU shall be attached and connected via the interfaces defined in TBS.

c) The MCU will be operable after sustaining loads derived from the launch environments described in section 3.4.1.

d) The MCU will operate under on-orbit interface loads derived from the load environments described in section 3.4.2.

e) The MCU will dissipate less than 100W average to the MCU mechanical interface when the MCU is powered but the GA is idle and the cameras and lights are powered off.

f) The MCU will dissipate a maximum of 150W peak to the MCU mechanical interface when the MCU is powered, and the GA is active and the cameras and lights are powered on.

g) The MCU will operate as specified when mounted to a surface with a temperature range of –10 to +35 deg C and a minimum thermal conductance of 12.0 W/deg C.

3.2.1.2 Electrical Interfaces

3.2.1.2.1 MA to MCU

a) The MA electrical interface to the MCU shall be via a subsystem interconnection cable that connects the GA to the MCU.

3.2.1.2.2 GA to Dexterous Robot (DR)

a) The GA will interface with the DR via the interface defined in Appendix C. This interface will transfer power, data and video.

3.2.1.2.3 MCU to HRV

This interface is illustrated for reference in Figure 3.

a) The MCU electrical interface to the spacecraft shall be via an interconnection cable that shall be supplied and installed by the HRV Systems Integrator.

b) The pin allocation of this interface shall be as defined in Appendix B.

c) The manipulator subsystem will be designed to operate at 28+/-6V directly from the spacecraft power bus compliant with MIL-STD-461C.

d) The telemetry, command and control interface to the MCU shall be performed via the HRV Data Bus.

e) Video image data shall be transferred to the HRV in accordance with Appendix B. Video may be transferred as an analogue NTSC signal or selected images may be captured, digitized, stored and transferred via a video data Bus.

f) In addition, the MCU shall have discrete signal interfaces as defined in Appendix B to support the following functions:

i) Emergency Stop

ii) Backup EE Release

iii) Backup Joint Drive

g) The electrical characteristics of the HRV Data Bus and the HRV Video Bus shall be as defined in Appendix B.

h) The data formats and data rate of the HRV Data Bus and the HRV Video Bus shall be as defined in Appendix D.

3.2.1.2.4 GA Manipulator Arm to HRV and DR

The GA to HRV electrical interface is shown for reference in Figure 3.

a) The GA electrical interface to the spacecraft shall be via an interconnection cable that shall be supplied as GFE.

b) The pin allocation of this interface shall be as defined in Appendix A1.

c) The manipulator subsystem will transfer power to the DR interface at 28+/-6V directly from the spacecraft power bus compliant with MIL-STD-461C.

d) The manipulator subsystem will transfer telemetry, command and control to and from the DR interface via the DR Data Bus.

e) The manipulator subsystem shall transfer Video image data from the DR to the HRV in accordance with Appendix A1. Video may be transferred as an analogue NTSC signal or selected images may be captured, digitized, stored and transferred via a video data Bus.

f) The manipulator subsystem will transfer discrete signals to the DR as defined in Appendix A1.

g) The electrical characteristics of the HRV Data Bus and the HRV Video Bus shall be as defined in Appendix B.

h) The data formats and data rate of the DR Data Bus and the Video Bus shall be as defined in Appendix D.

3.2.2 (Section Not Used)

3.3 Operational Interface Characteristics

3.3.1 Operational Sequence Interfaces

Under normal conditions, the mission proceeds according to a scheduled sequence in which the Hubble Robotics Vehicle (HRV) Mission Manager sends commands to the MCU to perform specific operations.

a) The MCU will contain a library of pre-planned operations or scripts, which shall be called in any sequence by the HRV Mission Manager.

b) The library will contain the scripts defined in Appendix D.

c) While a script is being executed, the MCU shall provide its status by telemetry data to the HRV Mission Manager indicating which step is in progress.

d) The MCU shall provide manipulator telemetry during Standby and Operate States per Appendix D.

e) The MCU will be capable of updating its script library with new scripts uploaded from the SGS via the Space Telescope Operations Control Center (STOCC).

3.3.2 HST Capture and Berthing Operational Interfaces

3.3.2.1 Task Definition

HST Capture includes maneuvering the GA to the designated initial position from its parked pose, acceptance of handover from the spacecraft to initiate capture, maneuver to the **pre-capture position** (within the capture envelope of the end effecter), capture of the HST, and positioning of the HST at its berthing location (within the capture envelope of the berthing mechanism for the HST on the HRV).

Berthing includes compliance to the berthing action of the HRV berthing mechanism, followed by release of the HST and a return to the parked pose.

The manipulator subsystem is capable of on-orbit execution of these operations, in concert with the HRV Mission Manager per Section 3.3.1 above, when they have been planned using the SGS with capabilities as defined in Section **Error! Reference source not found.**.

3.3.2.2 HST Capture

The GA will be capable of performing the following functions during HST Capture, subject to the constraints specified in section 3.3.2.3:

a) Capturing the HST via its grapple fixture interface when the handover conditions are satisfied.

b) The elapsed time to capture the HST from the moment the HRV provides the command to initiate capture will be less than 2 minutes. Capture is complete when the GA has successfully rigidized to the HST grapple fixture.

c) Decelerating the captured HST to rest with respect to the HRV, once the HST has been captured.

d) Aborting the capture attempt if the handover conditions are violated or the MCU determines that the capture attempt has failed.

e) Positioning the HST within the capture envelope of the HRV berthing mechanism, as defined in Appendix A2.

3.3.2.3 Hand Over Interface

The manipulator will be capable of performing the functions specified in section 3.3.2.2, subject to the listed handover conditions, applicable when the SGS is given the 'GO' for capture:

a) Relative rates between HST and HRV as per Table 3 (the pre-capture position may be plotted in advance by HRV GN&C sensing and the HRV Mission Manager).

b) Relative alignment of HST and HRV per Appendix A2.

c) Lighting conditions are controlled. These conditions are either eclipse or a sunlit condition where the HST and HRV orientations are selected to preclude shadows on the GF target during the capture sequence.

d) Both satellites are in free drift or have a control authority less then 100 mN-m. HRV ACS may be reactivated when the GA has decelerated the HST to within a selected threshold rate with respect to the HRV and has applied the joint brakes.

The manipulator will be capable of performing the functions specified in section 3.3.2.2e, subject to the following additional constraints:

e) The access envelope through which the manipulator moves in order to capture and position the HST within the capture envelope of the HRV berthing mechanism is defined in Appendix A2. The HRV Systems Integrator shall control the configuration of the spacecraft such that the Solar Arrays and any other spacecraft appendages are not obstructions to the required manipulator motions, as they are specified in this document and in Appendix A2.

f) HRV and HST mass properties are within the ranges specified in Table 4.

3.3.2.4 HRV Berthing Mechanism Back-drive of the GA

After the GA has positioned the HST in the HRV berthing mechanism capture envelope, the HRV berthing mechanism generates forces and moments at the HST berthing interface that align the HST to the HRV. During the alignment segment of the berthing task, the GA is back-driven by the forces and moments seen at the tip of the GA. These GA tip reaction forces contribute to the resistive loading on the HRV berthing mechanism during HST alignment.

a) When the GA is in the configuration required to position the HST within the HRV capture envelope (manipulator configuration as specified by Appendix A2) it will back-drive when loads of the following magnitudes are applied to its tip:

   i) A pure force of 130 N, or

   ii) A pure moment of 160 Nm

b) The manipulator will be capable of releasing the grapple fixture on the HST after the berthing action of the HRV has completed successfully.

3.3.3 Servicing Interfaces

3.3.3.1 Task Definition

DR Capture includes maneuvering the GA to the designated high hover position from its parked pose, maneuver to the pre-capture position (within the capture envelope of the end effecter), and capture of the DR electro-mechanical Grapple Fixture. Capture includes establishing required electrical connections and GA compliance to the capture functions.

DR Positioning includes maneuvering the GA with DR, and DR payload, to designated worksite positions, as well as stowing the DR in a designed location. Positioning also includes reacting loads induced by DR operations.

3.3.3.2 Service Positions Enabled by HRV Packaging

The GA shall be unencumbered by the HRV while performing the following functions:

a) Not Used.

b) Not Used.

c) Positioning the DR at the designated worksites defined in Appendix A2.

d) Positioning the DR and its payload at the designated worksites defined in Appendix A2.

e) React loads induced by the DR during operations at the worksites.

3.3.3.3 DR Capture/Removal/Re-stow Constraints on HRV Packaging

The manipulator will be capable of performing the functions listed in section 3.3.3.2, subject to relative alignment of the GA and DR for DR capture as defined in Appendix C.

3.3.4 GA Operational Boom Stiffness and Damping

A parametric trade study of GA boom material stiffness and outer diameter has been performed in support of studying the timeliness of HST servicing task accomplishment. For the two 16 foot (TBR – HRV GN&C) boom lengths desired, the cross-sectional stiffness parameters modeled for HST Servicing tasks are:

Longitudinal	EI	term	>	1.0E9	lb-in^2
Torsion	GJ	term	>	0.6E9	lb-in^2

For aluminum alloy 6061-T6 with Inner Diameter (ID) of 6.80" and Outer Diameter (OD) of 8.00", each 16 foot boom section is estimated to weigh 178 pounds. The estimate mass allocation for the GA, and the graphical layouts of the GA have assumed these component mass and OD parameters.

Servicing planning has assumed 5% of critical mechanical damping for the overall Mechanical Arm (MA) portion of the GA. MA Joint losses through mechanisms and MA exterior cables that traverse the Joints are assumed to account for elevated damping, as compared to what is typically assumed for structure-only (0.5% to 2% for pure structure).

3.3.5 VSR Commands from HRV

The GA will provide the following Video Sequence Recording (VSR) capabilities:

a) The capability to digitally record video sequences from an GA camera when commanded to do so by the HRV.

b) Recording rate of up to 10 JPEG-encoded frames per second with compression.

c) Recording time of at least 120 seconds.

3.3.6 Video Sequence Transfer to HRV

a) The GA shall transfer recorded video image data to the HRV when commanded per Appendix D.

b) The video image transfer format and data rate shall comply with Appendix D as defined in Section 3.2.1.2.3.

3.4 Environmental Interfaces

3.4.1 Launch/Ascent Phase

The launch environment for the GA interface to the HRV is defined in the following subsections. The launch environments described in section 3.4.1.2 has been estimated using data from an EELV PPG.

3.4.1.1 (Section Not Used)

3.4.1.2 Interface Vibration

3.4.1.2.1 Interface Low-Frequency Vibration

The GA will be designed for the estimated low-frequency quasi-sinusoidal launch vibration conditions presented in Figure 5a.

3.4.1.2.2 Interface High-Frequency Random Vibration

The GA will be designed for the high-frequency random launch vibration conditions presented in Figure 5b.

3.4.1.3 Interface Shock Received by the GA

The GA is assumed to be 3 mechanical interfaces away from the primary sources of shock and will be designed to operate after being subjected to 5% of the input shock conditions as defined in Table 7.

3.4.1.4 (Section Not Used)

3.4.1.5 (Section Not Used)

3.4.1.6 Interface Temperature at Launch

The GA will be designed for the following non-operating temperatures during launch and ascent:

Maximum +85 °C

Minimum -10 °C

3.4.2 On-orbit Phase

3.4.2.1 (Section Not Used)

3.4.2.2 Cosmic Radiation Protection from HRV

a) The GA will be designed to operate during nominal space radiation conditions.

b) Normal operation will allow transition to a safe-state should functional interruption occur. The GA shall be placed in the survival-state (shutdown) for solar particle events.

c) The GA will be designed to survive mission total ionizing dose as defined in trapped proton and electron models.

3.4.2.3 Micrometeoroid and Debris Shielding from HRV

a) The components of the GA external to the HRV will be designed to survive, with a 95% probability of no failure, for the on-orbit lifetime.

b) The man-made debris environment is not a design driver and will not be analyzed.

3.4.2.4 Thermal Operational Interface

a) The GA will operate continuously (Operate State) while in continuous sunlight plus earthshine corresponding to spacecraft orientation in a solar-inertial attitude control mode.

b) The GA will survive while non-operating (Initialize or Standby State) and/or operate continuously (Operate State) while in maximum eclipse with albedo and earthshine corresponding to spacecraft stabilization in a solar-inertial attitude control mode.

c) The GA will survive while non-operating (Initialize or Standby State) and/or operate continuously while in maximum eclipse/ continuous shadow of the spacecraft with albedo and earthshine corresponding to spacecraft stabilization in an earth-pointing attitude control mode with the D1-axis facing the earth.

3.4.2.5 Electromagnetic Interfaces

The GA will be designed to meet Conducted Emission (CE01, CE03), Conducted Susceptibility (CS01,CS02, & CS06) Radiated Emission (RE02) and Radiated Susceptibility (RS03) levels as defined in MIL-STD-461C.

3.4.2.6 (Section Not Used)

3.4.2.7 HRV Constraints While GA Operates, On-orbit Loads

a) The GA will operate as specified herein when subjected to the motion disturbances detailed in Table 6 applied at the mounting interfaces.

b) While brakes are engaged, the GA, with or without maximum payload attached, will maintain its position (zero joint gear train back driving) and not suffer damage when subjected to the following loads due to HRV thruster firings applied at the shoulder mounting interface:

   i) Force of 40N, maximum, in any direction.

   ii) Moment of 40 Nm, maximum about any axis.

   iii) These loads shall not be repeated (pulsed) in the frequency range 0.05 Hz to 3.0 Hz.

3.5 Design of Interface between GA & HRV

3.5.1 Mass Allocation for GA

The GA will not exceed 1,455 pounds for the MA including cables, lights, and cameras. The GA will not exceed 45 pounds for the MCU.

3.5.2 Power Allocation for GA

a) The GA shall draw a maximum of 100W average from the GA Operational Power input when the GA is powered but the MA is idle and the camera and lights are powered off.

b) The GA shall draw a maximum of 210W peak from the GA Operational Power input when the MA is not idle, and the camera and lights are powered on.

c) The power draw from the GA Thermal Control Power input for survival will not exceed 200W peak and 70W orbital average.

3.5.3 (Section Not Used)

3.5.4 Interface Design and Analysis

3.5.4.1 Interface Load Cases

Four main load cases shall be considered in the structural analysis:

a) Ground handling and test.

b) Launch and ascent as defined in Section 3.4.1 with the loads combined as follows:

   i) acceleration combined with vibration (random or acoustic as applicable) in a root sum square fashion.

   ii) thermal loads resulting from the liftoff thermal environment combined with the RSS sum of quasi-static and vibro-acoustic components.

c) Normal on-orbit operational conditions as defined in Section 3.4.2. The structural analyses shall combine thermal loads due to the operating thermal environment with dynamic loads as applicable.

d) Abnormal on-orbit operational conditions.

3.5.4.2 Interface Safety Factors

Safety Factors shall be applied to the maximum predicted loads or stresses determined for the above load cases. The Safety Factors used in the stress analysis are:

a) FS for yield strength: 1.25

b) FS for ultimate strength: 1.5

3.5.4.3 Interface Margins of Safety

The structural adequacy of each component shall be determined by its Margin of Safety which is defined by the following equation:

$$MS = \frac{\text{Allowable Load or Stress}}{\text{Maximum Predicted Load or Stress * SF}} - 1$$

where: SF is the Safety factor

Allowable is the maximum permitted for yield, ultimate, buckling, etc.

Margins of Safety for each component shall be greater than or equal to zero.

3.5.4.4 Interface Materials of Construction

The material properties used in the analyses shall be the minimum relevant values obtained in accordance with MIL-HDBK-5 and MIL-HDBK-17.

3.5.4.5 Interface Stowed Natural Frequencies for GA in the HRV Hold-Down Devices

The stowed manipulator will have a natural frequency of at least 20Hz, when supported rigidly at the points defined in Section 3.2.1.1.1, to avoid resonance with the main spacecraft vibration modes during launch.

3.6 Interface Operational Fault Tolerance

a) No single failure of the GA interface will propagate to the HST and render it incapable of performing science.

b) The GA will be designed so that it does not represent a hazard to ground operators or test personnel.

c) No single non-mechanical failure of the GA or erroneous command will cause an unintended movement of the manipulator when it is stationary.

d) No single non-mechanical failure of the GA or erroneous command will cause a deviation from its commanded trajectory of greater than 180 mm, even when an emergency stop is commanded.

e) The GA shall provide a backup capability for the HRV spacecraft computer to power GA joints and the end effecter release function.

f) The GA-MCU shall be augmented by the HRV spacecraft computer, operating single joints, to supply functional redundancy for all GA operations, except grapple of HST if HST is not controlled, or existing, in an inertial frame. GA cameras and lights may be positioned in single joint mode to support the HRV contingency of conducting direct berthing mode.

Table 1: GA Mission Profile Summary

Mission Phase	Subsystem State	Duration	Main Events/ Activities	Important Environments
Prelaunch	Off	6 months	• (Integration with spacecraft) • (Integration with launcher) • Final checkout	• Transport and handling loads. • Storage temp and humidity • Cleanliness/ contamination
Launch	Off	1 day	• (Lift-off) • (Ascent) • (Separation of spacecraft from launcher)	• Accel, vibration and shock. • Acoustic noise • Rapid depressurization • Temperature change
On-orbit	Initialize, Standby	1 day	• Power On • Passive checkout	• Space vacuum • Cosmic radiation • Survival temperatures
On-orbit	Operate	12 months	• Deployment • Checkout • Calibration • Operation	• Base motion disturbance • Cosmic radiation • Operating temperatures • EMC
Descent and re-entry	Off	1 day	• Burn up prior to arrival at surface of earth	• Burn up temperatures

Table 2: Summary of States and Available Functionality

	MCU Powered	MAA Thermal Control Active	MAA Telemetry Available	MCU Software can be Uploaded/Initialized	Cameras and Lights available	Manipulator Motion Control Modes Available	Diagnostic Features Available
Off							
Initialize State	X	X		X			
Standby State	X	X	X		X		
Operate State	X	X	X		X	X	X

Table 3: Handover Preconditions

Parameter	Unit	Value
Inner Capture Box centroid position relative to shoulder		Per Appendix A1
Inner Capture Box Size relative to its centroid (x, y, z)	m	+/- 0.25, 0.25, 0.25
Angular misalignment in Inner Capture Box relative to its centroid (x, y, z)	deg	+/- 3, 3, 3
Relative velocity in Inner Capture Box (x, y, z)	m/s	+/- 0.02, 0.02, 0.02
Relative angular velocity in Inner Capture Box relative to its centroid (x, y, z)	deg/s	+/- 0.25, 0.25, 0.25

Table 4: Payload Characteristics

Parameter	Unit	Value
HST Mass	Kg	11500 to 12500
HST CofG relative to HST axes (V1, V2, V3)	M	7, 0.5, 0.5, maximum
HST Inertias about CofG (I_{V1}, I_{V2}, I_{V3})	Kgm^2	36000 to 39000, 88000 to 89000, 93000 to 95000
HRV Mass	Kg	6800 to 18000
HRV CofG relative to MAA base (x, y, z)	M	2 ±0.5, -0.5±0.5, 0±0.5
HRV Inertias relative to CofG (Ixx, Iyy, Izz)	Kgm^2	13000 to 55000, 14000 to 38000, 13000 to 55000
DR Mass	Kg	1800
DR Payload Mass	Kg	550 maximum
DR Payload Inertias relative to GF (V1, V2, V3)	Kgm^2	500 maximum

Table 6: On-orbit Vibration Spectrum

Frequency (Hz)	**Acceleration Spectral Density ($m^2/s^4/Hz$)**	**Angular Acceleration Spectral Density ($rd^2/s^4/Hz$)**
0.01to 0.09	1.27E-9	1.27E-9
0.1 to 0.9	1.27E-8	1.27E-8
1.0 to 9.0	1.27E-7	1.27E-7
10 to 100	1.27E-8	1.27E-8
100 to 1000	1.27E-9	1.27E-9

Table 7: Maximum Shock at the GA Interfaces

Frequency (Hz)	**SRS Level (g's)**
100	50
1,300	3,500
10,000	3,500

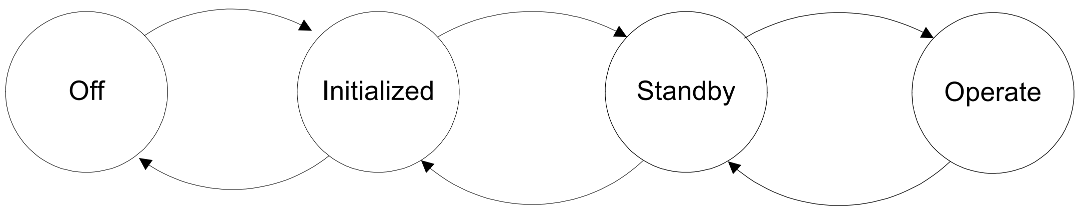


Figure 2: GA Top Level State Transition Diagram

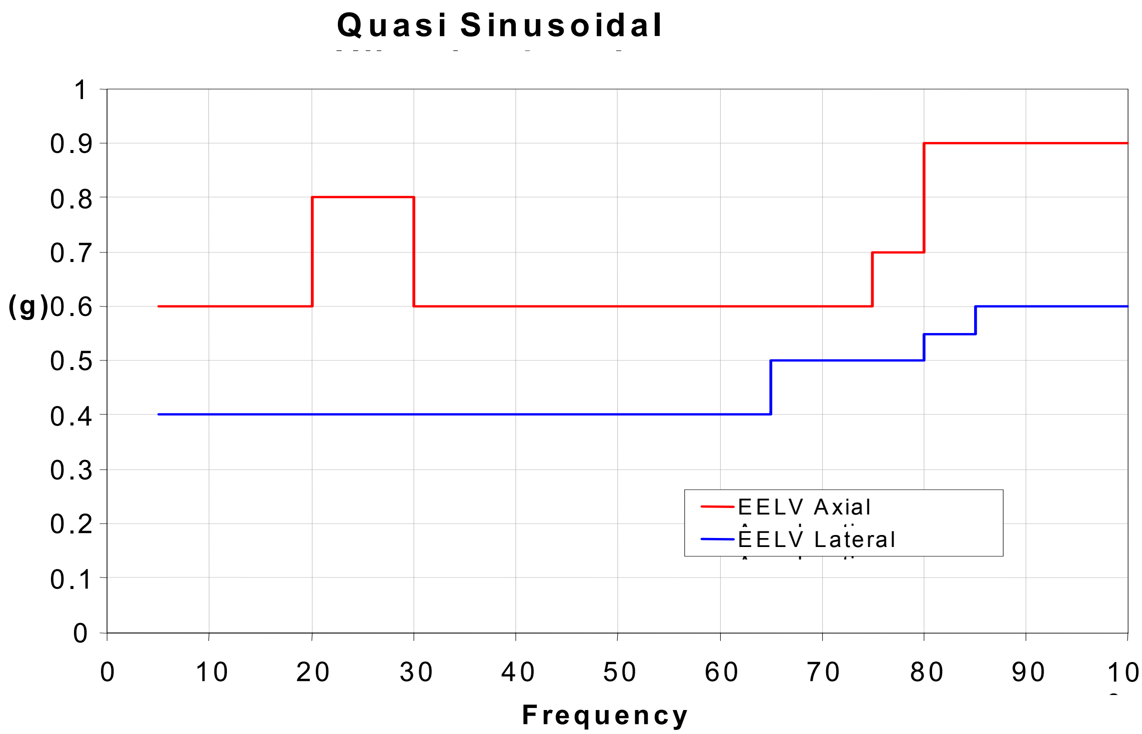
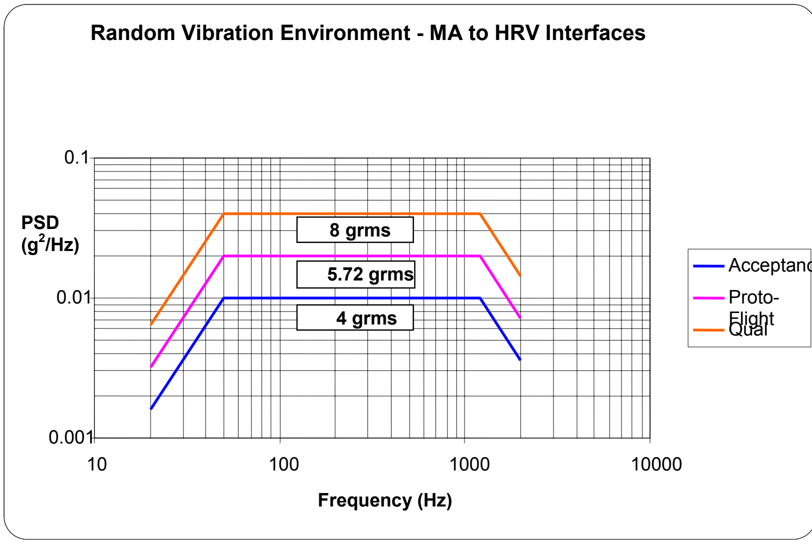


Figure 5a: GA Low-Frequency Vibration Spectrum



Frequency (Hz)0	PSD (g^2/Hz)
20 20 – 50 50 – 1200 1200 – 2000 2000	0.0016 + 3 dB/octave 0.01 – 6 dB/octave 0.0036
Acceptance	4 grms
Duration (Acceptance/Proto-flight)	60 seconds along each axis (x,y,z)

Figure 5b: GA Random Vibration Spectrum

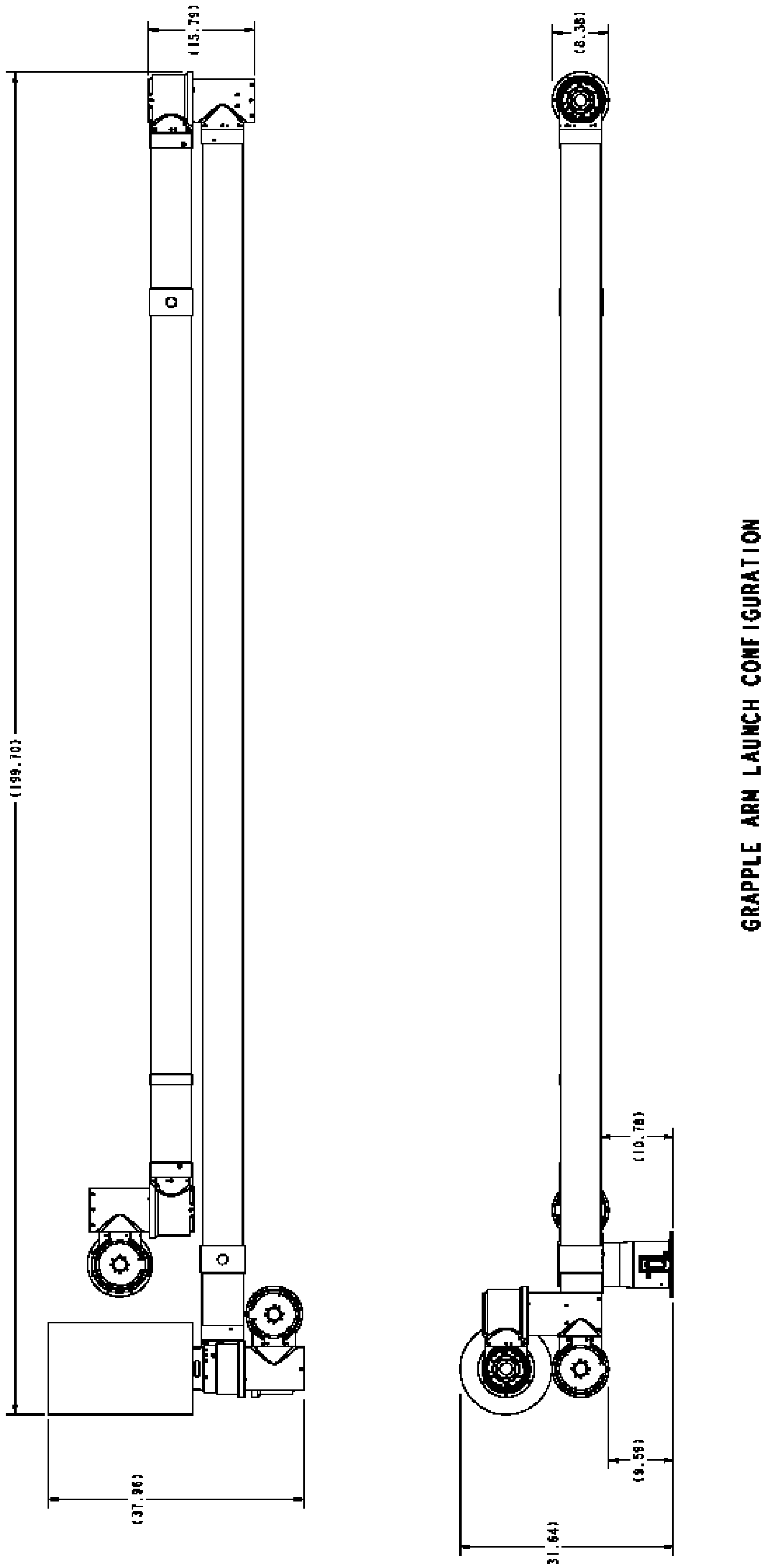
4 (Section Not Used)

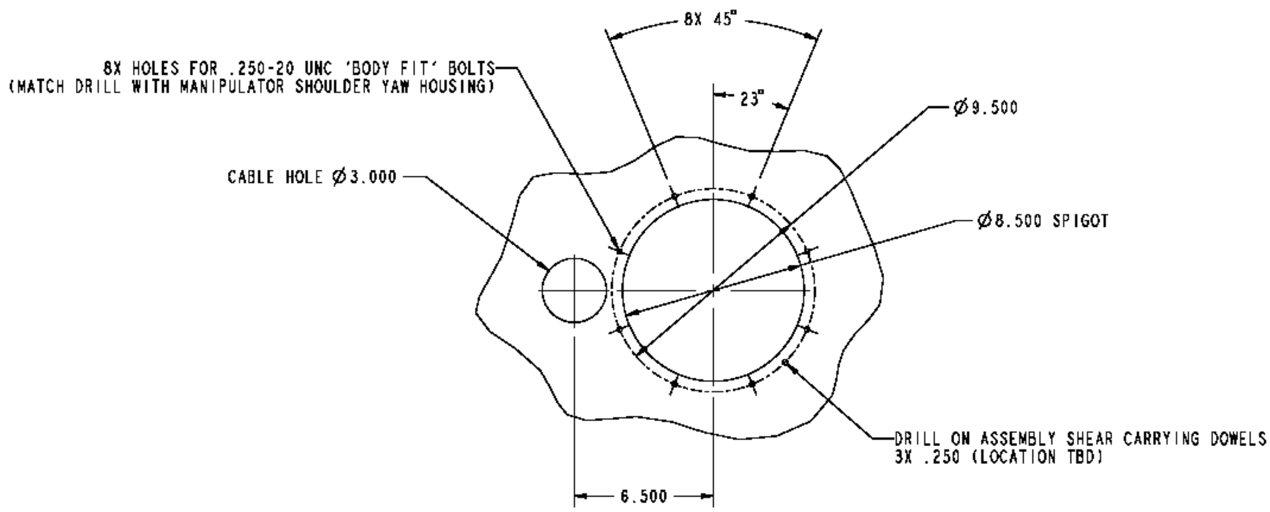
5 GROUND HANDLING INTERFACES

The GA shall be protected to survive without damage or degradation of performance and meet the requirements specified herein after exposure to the on ground conditions specified below:

(i)	Temperature:	Maximum +85 °C Minimum –10 °C
(ii)	Pressure:	Maximum 104.8 kPa Minimum 67.6 kPa
(iii)	Relative Humidity (non-condensing):	Maximum 100% Minimum 8%

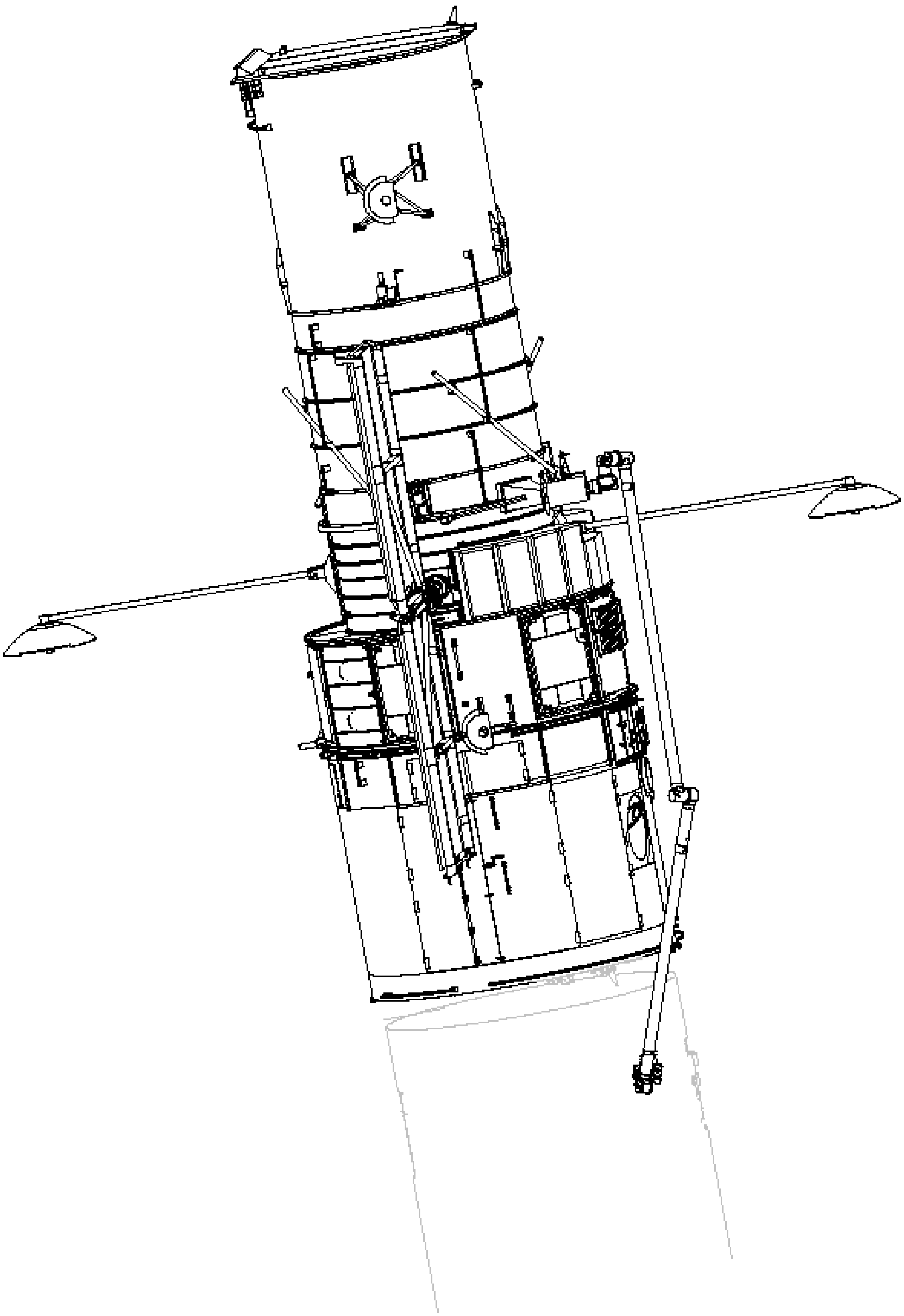
Appendix A1 HRV to GA Electro-mechanical Interface



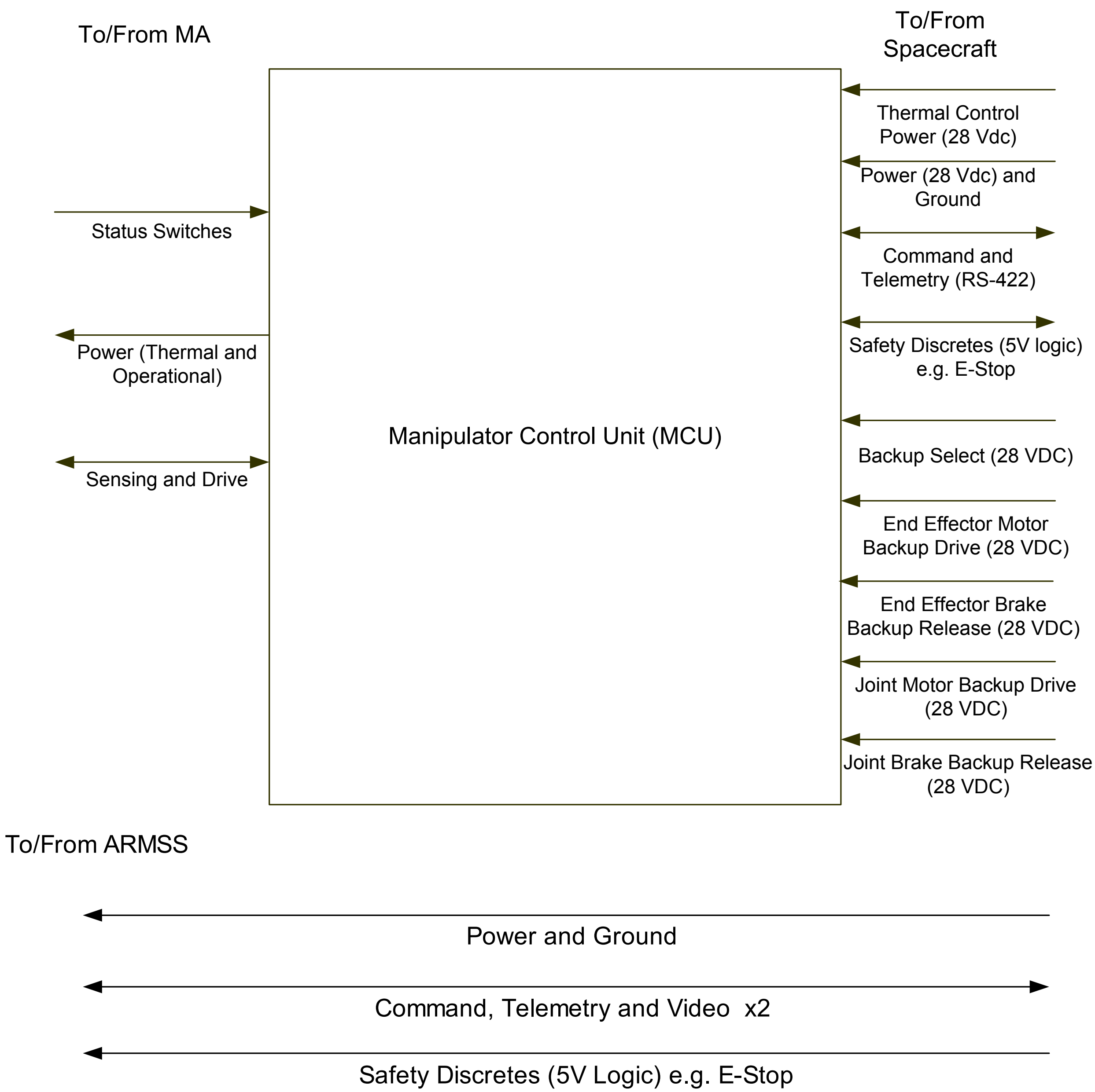


GRAPPLE ARM MATING INTERFACE

Appendix A2 GA Workspace Access to HST

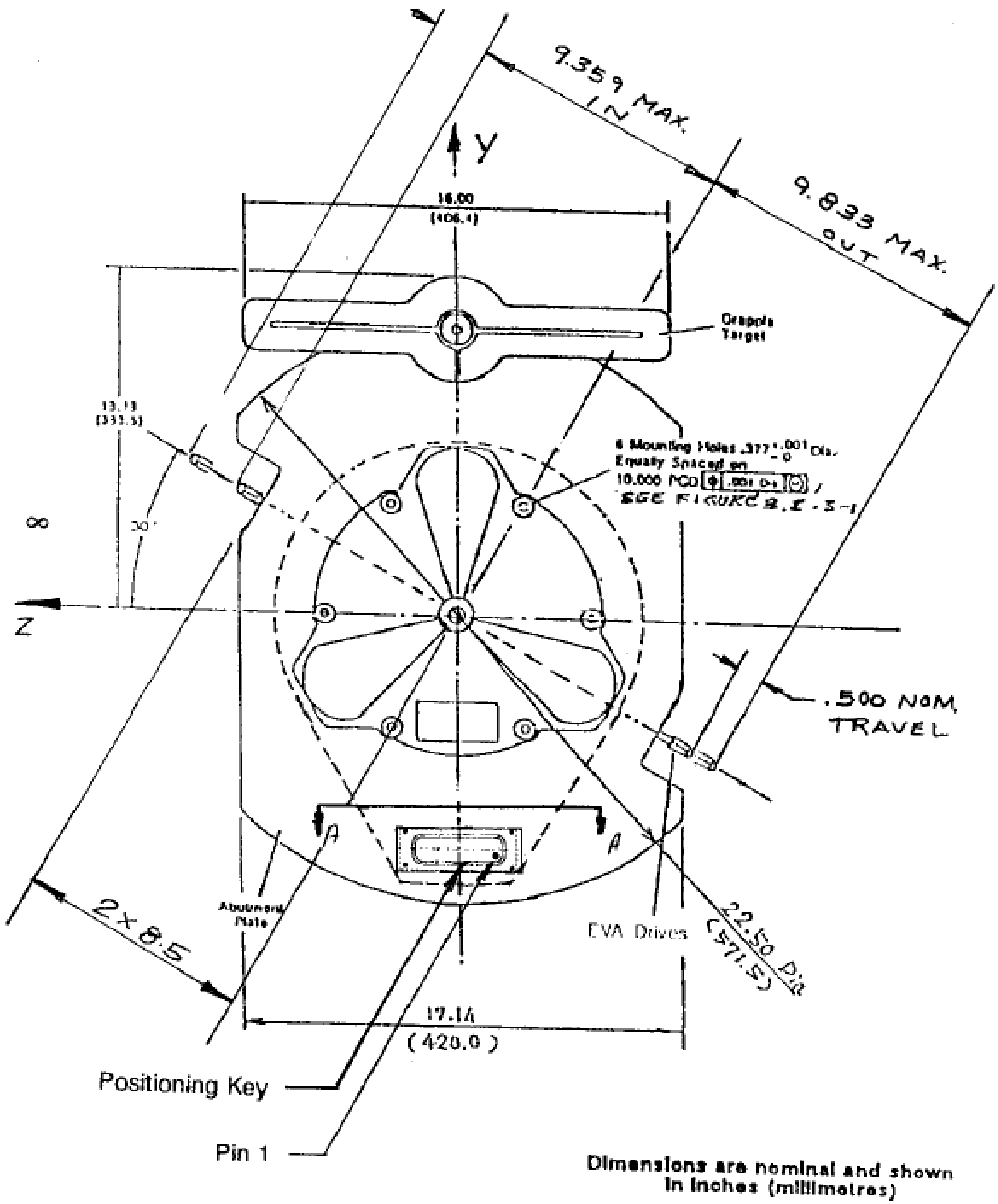


Appendix B HRV to GA-MCU & GA-Cables Electro-mechanical Interface



Appendix B: MCU and MA Electrical Interface

Appendix C -- GA to DR Electro-mechanical Interface



GRAPPLE ARM TO DEXTROUS ARM MECHANICAL INTERFACE

Appendix D -- STARSS (GA + DR) to HRV Data Interface

D1 Scope. The STARSS is a robotic system used for Hubble Space Telescope servicing. The robotic system will reside on the HRV. This document describes the necessary interaction between the HRV and the STARSS software components to perform these functions.

D1.1 Identification

This Interface Control Document (ICD) specifies the data interface of the Computer Software Configuration Items (CSCIs) for the Space Telescope Advanced Robotic Servicing System within the Hubble Robotic Vehicle program.

The interface defined is the interface between the STARSS Flight Segment Software and the HRV, and between the STARSS Flight Segment Software and the STARSS Ground Station (SGS) Ground Segment Software via the HRV and downlink system.

D1.2 System Overview

The Space Telescope Advanced Robotic Servicing System (STARSS) is a subsystem of the Hubble Robotic Vehicle (HRV). The STARSS consists of an on-orbit robotic system (including the avionics), and a ground station. The STARSS is capable of performing the following functions in the context of the HRV System:

d) Capture, positioning and release of the HST;

e) HST servicing functions;

f) Recording JPEG video images from the STARSS cameras.

The flight software will perform the functions of robotic control as well as vision functionality to help determine object location for HST capture. The Ground Segment CSCI will enable ground interaction and script creation to aid in control of the robotics.

D1.3 Document Overview

This document covers the Interface Control description for the STARSS external data interfaces.

The format and content of this document is based on DOD-STD-498 Data Item Description for the Interface Design Description (DI-IPSC-81436). This ICD is organized as follows:

1) Section 1, Scope

   Identifies this document, its scope and purpose.

2) Section 2, Referenced Documents

   (Deleted)

3) Section 3, Interface Design

   This section describes the interface characteristics of one or more systems, subsystems, configuration items, manual operations, or other system components.

4) Section 4, Requirements Traceability

   (Deleted).

5) Section 5, Notes

   (Deleted).

6) Appendices.

(Deleted)

D3 Interface Design

This section details all the external data interfaces with the STARSS system. Section 3.1 details the data interfaces, both discrete and serial, that the STARSS has with the host processor, the HRV Mission Controller. Section 3.2 gives the details of the data interfaces of the SGS with the host network, TBD Goddard Control Center. Section 3.3 gives details of the Mission Scripts that are created by the SGS and utilized by the STARSS.

D3.1 STARSS External Interface Description

Table D 1 gives an overview of the external interfaces shown in the STARSS to HRV Electrical Interfaces, Figure D 1.

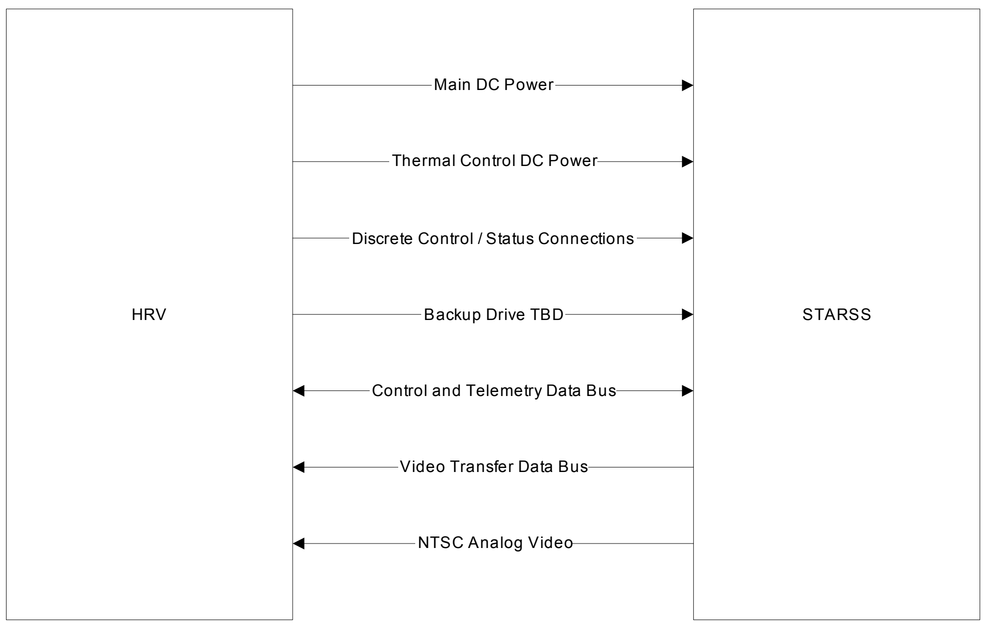


Figure D 1: STARSS to HRV Electrical Interface

Table D 1: Top Level Interfaces Definition

Name	Destination	Path	Method	Description
Software Watchdog Status	HRV	Direct	Discrete	Signal from the I/O Board. An asserted signals means that the processor board is communicating properly with the I/O Board and that the software is running. Needs to be used in conjunction with the MCU Software Initialized signal.
MCU S/W Initialized	HRV	through MCU I/O Board	Discrete	Signal signifying that the MCU software is has started running.
Enable / Emergency Stop	MDA	Direct	Discrete	Signal to enable / disable all arm movement and allow for disengaging the brakes. (Signal is also forwarded by the MDA and I/O boards to the Processor.)
HRV Mission Status Packet (TBD)	MCU Processor	Serial Data Bus	Serial	Various status information and commands that the MCU needs from the HRV (TBD)
MCU Outputs (See Serial Comm Roll Up Table)	HRV	Serial Data Bus	Serial	Any possible status information needed by the HRV from the MCU (like visual capture box achieved)
MCU Inputs (See Serial Comm Roll Up Table)	MCU Processor	Serial Data Bus via HRV	Serial	All commands and non-predefined scripts being sent to the MCU.
MCU Outputs (See Serial Comm Roll Up Table)	SGS	Serial Data Bus via HRV	Serial	All telemetry being sent down the Ground Station as well as command responses.
Analog Video	HRV	Direct	NTSC	NTSC video sent to the HRV from STARSS cameras
Digitized Video (See Serial Comm Roll Up Table)	SGS	Serial Data Bus via HRV	JPEG Image Files	This is stored digitized and compressed video data from the cameras.

D3.1.1 STARSS Serial Data

The STARSS data bus will be full-duplex 115.2 kbps with even parity, 1 stop-bit, and 8 data bits. Flow control will not be utilized. The STARSS video bus will be half duplex 115.2 kbps with even parity, 1 stop-bit and 8 data bits. The maximum number of image files sent over the video bus will be 2200. A break-down of the serial data is detailed in

Table D 2. Serial data transferred between the STARSS and the SGS are meant to come via the TBD Goddard Ground Segment and the HRV. There is no direct connection from the SGS to the STARSS.

The HRV will be expected to forward all currently received telemetry packets when the STARSS is in operate state and the HRV has good communication with the ground segment. All STARSS status packets received when the STARSS is in standby state, all video, and all other telemetry packets will be stored for download after the scenario is completed. The telemetry packets and video will be stored by the HRV for archived playback on the SGS and the STARSS status packets will be stored for access by engineers in case of a problem in the scenario during standby state.

The STARSS serial inputs are made up of all serial messages that the STARSS can receive. They are listed in Table D 3. Likewise, the STARSS serial outputs are made up of all the serial messages that the STARSS can transmit and are listed in Table D 4.

Table D 2: STARSS Serial Comm Roll Up

Serial Direction	Serial Bus	Type	Source	Dest.	Max Size (bytes)	Description	Occurrence	Applicable System State
STARSS Inputs (see STARSS Inputs Table for more detailed information.)	Data Bus	ExecutiveCommands	SGS or HRV	STARSS	96	ie Script Execution Controls, Light On/Off (can be issued from ground or from HRV)	As needed	Standby, Operate
		Parameter Set Up	SGS	STARSS	1024		As needed (not necessary for normal operation)	Standby
		New Script File Upload	SGS	STARSS	1024		As needed (not necessary for normal operation)	Standby
		Software Upload	SGS	STARSS	2 M		As needed (not necessary for normal operation)	Standby
		HRV Mission Sequence Status	HRV	STARSS	22		As needed	all states (excluding OFF and Initialize)
STARSS Outputs (see STARSS Outputs Table for more detailed information.)	Data Bus	Telemetry Packet	STARSS	SGS	3040	TBD x 304 byte Telemetry Packets sent every 500ms	2 Hz continuous	Operate, Initialize
		Response	STARSS	SGS or HRV	48	Response to any STARSS input	As needed	all states (excluding OFF)

Serial Direction	Serial Bus	Type	Source	Dest.	Max Size (bytes)	Description	Occurrence	Applicable System State
		STARSS Status	STARSS	HRV	58	Provides HRV with script segment ID and other pertinent status info. This will also contain Request_for_Status.	2 Hz continuous	all states (excluding OFF and Initialising)
Video	Video Bus	DigitalVideo	STARSS	SGS or HRV	31k per image	JPEG-encoded image files	Upon request by HRV	Standby, Operate

Table D 3: STARSS Inputs

Grouping	Command Name	Parameters	Description	Available From SGS
ExecutiveCommands	Run Script	Script ID, Script Checksum, Current UTC Time, Verify Initial Conditions (T/F)	Begins executing the script identified in the ID parameter .The Current UTC time is used to synchronize the MCU clock.	Yes
	Stop Script	Script ID, AfterCurrentScriptElement (vs. immediately)	Stops the currently-executing script with brakes applied and does not allow it to restart. "Immediately" mode should only be used in emergency situations.	Yes
	Pause Script	Script ID, AfterCurrentScriptElement (vs. immediately)	Stops the currently-executing script, with brakes applied, allowing it to restart using Resume Script. "Immediately" mode should only be used in emergency situations.	Yes
	Resume Script	Script ID (must match currently paused script)	Resumes paused script (some scripts cannot be resumed, for example visual servoing)	Yes
	Start Recording	Camera ID, Period, Current UTC	The period specifies the time (in 1/10ths of seconds) between the saving of video images when recording. Range of the period is 0 to 999 inclusive which means 1-1000 tenths of seconds. The Current UTC time is used to synchronize the MCU clock. This is also available via script element.	No
	Set Light State	Light ID, On/Off	This is also available via script element	No
	Transfer Video		Transfer entire buffer of recorded video.	No
	Pause Recording		Pauses video recording. When re-started the images will be saved at the point in the image buffer where it was paused.	No
	ShutdownMCU		Tells the MCU to backup data and shutdown.	No
	EnableRegOffset	Enable (T/F)	Applies the computed registration offset to all applicable POR moves	Yes
	Stop Recording		Stops video recording. When re-started the images will be saved at the beginning of the image buffer.	No
	Enter TeleOperation Mode		Instructs the MCU to enter teleoperation mode	Yes
	TeleOperation Control Message	X, Y, Z, Pitch, Yaw, Roll command input	Hand Controller Data when in TeleOperation Mode.	Yes
Parameter Set Up	Upload Control Parameter File	CtrlFileType, Control ID, Values	Uploads either a Controls Parameter File or a Controls Configuration File. The controls configuration file has an ID of 0.	Yes
	Upload Vision Parameter File	Vision ID, Values		Yes
	Upload System Parameter File	System ID, Values		Yes
New Script File Upload	Upload Script	Script ID, Script Length, Script, Script Checksum		Yes
	Replace Pre-loaded Script	Script ID, Previous Script Checksum, Script Length, Script, Script Checksum		Yes
	Delete Uploaded Script	Script ID, Script Checksum		Yes
Software Upload	Upload Executable	File Length, File, Checksum	The executable is uploaded.	Yes

Grouping	Command Name	Parameters	Description	Available From SGS
	Revert To Gold SW		Reverts to the original parameters, object libraries, executable software and scripts.	Yes
HRV Mission Sequence Status	New Status Info	Status Data	(Thrusters inhibited, ACS inhibited, etc.)	No

Table D 4: STARSS Outputs

Grouping	Command Name	Parameters	Description
STARSS Telemetry Packet	STARSS Telemetry Packet	Byte data	Telemetry data
Response	Run Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Stop Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Pause Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Resume Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Start Recording	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Set Light State	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Transfer Video	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Pause Recording	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	ShutdownSTARSS	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	EnableRegOffset	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Stop Recording	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Upload Control Parameter File	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Upload Vision Parameter File	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Upload System Parameter File	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Upload Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Replace Pre-loaded Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Delete Uploaded Script	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Upload Executable	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	Revert To Gold SW	Accept/Reject, ErrorData	Responses to the STARSS inputs.
	New Status Info	Accept/Reject, ErrorData	Responses to the STARSS inputs.
STARSS Status	STARSS Status Packet	Information (See STARSS Status Packets Contents Table)	Status and requests for acknowledgement needed for handshaking between HRV and STARSS
STARSS Video	Digital Video	Video Data(See Video Data Packet Table)	JPEG-encoded image files

D3.1.2 STARSS and HRV Status Packets

The HRV Mission Status Packet is a message that is sent from the HRV Mission Controller in response to a request included in the STARSS Status packet. It contains information about the current status of processes under the control or knowledge of the HRV processors. The STARSS Status Packet is a message sent from the STARSS to the HRV Mission Controller periodically at TBD (2) Hz. Its purpose is to update the HRV Mission Controller with information that it needs for control of the overall mission as well as for the STARSS to make requests for action by the HRV processors.

D3.2 SGS External Data Interface Definitions

The interface between the SGS and the TBD Control Center has not yet been defined.

D3.3 STARSS Mission Scripts Details

To support the required missions, the STARSS shall utilize STARSS Missions Scripts which are loaded in the STARSS prior to execution. The STARSS Mission Scripts will be created on the SGS and will utilize Script Elements as well as calls to Script Segments, which are groupings of Script Elements used to perform a portion of a mission.

The nominal STARSS Mission Scripts and Script Segments will be created on the SGS and then preloaded in the STARSS.

Appendix D's Acronyms and Abbreviations

CSCI	Computer Software Configuration Item
HRV	Hubble Robotic Vehicle
I/O	Input/Output
ICD	Interface Control Document
MCU	Manipulator Control Unit
MDA	Motor Drive Amplifier
SGS	STARSS Ground Segment
STARSS	Space Telescope Advanced Robotic Servicing System